point the c/a ratio is lowered below that value which β quartz[6] exhibits at 1000°C. Thermal and electrical evidence supports this view. Crystals bombarded by 5×10^{19} neutrons/cm^2 fail to exhibit the latent heat at the $\alpha\rightleftharpoons\beta$ inversion point and piezoelectric crystals no longer resonate after this irradiation.

Heavy dosages of fast neutron flux reduce all four of these solids to a common phase. This highly disordered material has an x-ray diffraction pattern of a glass, is optically isotropic, and has a density of 2.26. This material was recrystallized by annealing at 930°C for 16 hours and resulted in the formation of polycrystalline α quartz. Debye-Scherrer diffraction patterns taken using monochromatic radiation from a Cu target gave x-ray reflections at angles up to $2\theta=90°$. The fact that x-ray reflections were not observed at larger Bragg angles may be due to incomplete recrystallization, particle-size broadening, or strain. The contributions of each of these factors are being determined.

It appears that the bombardment of any of the above-mentioned phases produces a silica glass, with a density and average refractive index near that of normal low tridymite, which can then be transformed into α quartz in a solid-state reaction. Further annealing studies are necessary to confirm this view unambiguously. Such behavior would be of major interest since investigators[6] have been unsuccessful in their attempts to transform any of the complex silica phases into α quartz by means of a solid-state transformation in the absence of chemical aids.

A detailed report on the results of this investigation will be submitted for publication at an early date.

[1] R. Berman, Proc. Roy. Soc. (London) **A208**, 90 (1951).
[2] R. Berman, Advances in Physics **2**, 5, 103 (1953).
[3] M. Wittels, Phys. Rev. **89**, 3, 656 (1953).
[4] M. Wittels, Unpublished post-deadline paper, Washington D. C. Meeting, American Physical Society, May 2, 1953.
[5] Primak, Fuchs, and Day, Phys. Rev. **92**, 1064 (1953).
[6] R. B. Sosman, *The Properties of Silica* (Chemical Catalogue Company, Inc., New York, 1927).

Experimental Evidence Concerning Degeneracy in Germanium

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IN a recent note by Adams[1] it has been suggested that agreement of theory and experiment for germanium is such as to provide weak but definite evidence that the predicted degeneracy in the band structure[2] does not occur. It is the purpose of this note to point out that more recent measurements have modified substantially the stated points of agreement.

Measurements of lattice mobility taken on purer and presumably more prefect germanium samples show a variation with temperature as $T^{-1.6}$ for electrons,[3] $T^{-2.3}$ for holes,[4] instead of the $T^{-1.5}$ predicted by the deformation-potential theory[5] and other theoretical derivations. Along with other experimental results such as those for magnetoresistance and the anomalous ratio of Hall to drift mobility for holes,[3] this would seem to be explainable only on the basis of a more complicated picture of the band structure,[6] such as that predicted by Herman and Callaway. Such a band structure would result in shifts of the band edges with shear strains as well as dilatation.[5] In the light of these facts, the quantitative agreement found between the value of E_{1G} (the shift of the energy gap per unit dilatation) obtained from pressure experiments and that predicted by the deformation-potential theory for germanium would seem largely fortuitous. For silicon, it is worth noting, agreement was considerably poorer.

Agreement also apparently existed between values of β, the change in energy gap per degree change in temperature, determined from a few different types of experiment. The significance of this agreement is also open to question. One value of β was calculated from the experimental E_{1G} under the assumption that the change in energy gap with temperature was due entirely to thermal expansion. Another value of β is obtained from comparison of the theoretical formula

$$n_i^2=np=4\left(\frac{2\pi m_n^{\frac{1}{2}}m_p^{\frac{1}{2}}kT}{h^2}\right)^3 e^{-E_G/kT} \quad (1)$$

with n_i^2 calculated from measurements of intrinsic conductivity. With a $T^{-\frac{1}{2}}$ dependence for the lattice mobility and effective masses equal to the free electron mass, this led to a value of 1×10^{-4} ev/°K for β, in good agreement with the value calculated from E_{1G}.[5] Incorporating the changed temperature dependences of the lattice mobilities will change this value and worsen the agreement unless, of course, the effective masses used in (1) are changed. There is, however, a fundamental question as to whether or not these two values of β should agree; it has been shown by Fan[7] that the shift in the energy gap with temperature arises in part from the changing interaction of the electrons with the lattice vibrations.

If the band structure is not the simple kind usually assumed, Eq. (1) must be modified. It may well be that for some particular band structure the modification consists of the insertion of statistical weight factors for the conduction and valence bands as suggested by Adams.[1] The effective masses in the formula for n_i^2 should then represent suitable averages of effective masses over different bands or different directions. Unfortunately, however, the effective mass in other formulas may not be represented by the same average. Thus it appears that, in general, detailed knowledge of the band structure may be required for the determination of β from n_i^2.

A different value of β, 4×10^{-4} ev/°K, is obtained from measurements of infrared absorption.[7] If the band structure of germanium is that calculated by Herman and Callaway, it is not to be expected that this value of β agree with that obtained from thermal transitions.

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[1] E. N. Adams, II, Phys. Rev. **92**, 1063 (1953).
[2] F. Herman and J. Callaway, Phys. Rev. **88**, 1210 (1952).
[3] M. B. Prince, Phys. Rev. **92**, 681 (1953).
[4] W. C. Dunlap, Phys. Rev. **79**, 286 (1950).
[5] J. Bardeen and W. Shockley, Phys. Rev. **80**, 72 (1950).
[6] Pearson, Haynes, and Shockley, Phys. Rev. **78**, 295 (1950).
[7] H. Y. Fan, Phys. Rev. **82**, 900 (1951).

"Closed" Fountain Effect in Liquid Helium II*†

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THE rise in the liquid level of a closed system of helium II through which a heat current is passing has been observed. The rise is attributed to a stress which is the difference between

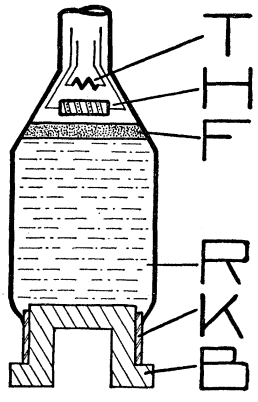

FIG. 1. Diagram of the closed, rouge-packed, glass-metal system.

the thermomechanical tension given by H. London's equation, $\Delta p=\rho S\Delta T$,[1] and a Hooke's law type stress.

Figure 1 is a diagram of the apparatus used. It consists of a glass tube which was packed with rouge powder (R) and which

was surrounded by a bath of liquid helium II. Sealed to the bottom of the glass is a Kovar tube (K) into which was soldered a brass plug (B). The purpose of the glass frit (F) was to serve as a porous barrier against which the rouge could be packed. Above this frit are a heater (H) and a carbon resistance thermometer (T). At the top the system is joined to a small-diameter glass tube which extends up through the helium flask.

Helium gas from an outside supply was condensed in the inner system in such an amount that the liquid level at zero heater power in the helium II temperature range was in and near the bottom of the small-diameter glass tube. The bath temperature was held constant in the liquid helium II range and the height and temperature of the liquid above the frit were observed as a function of heater power.

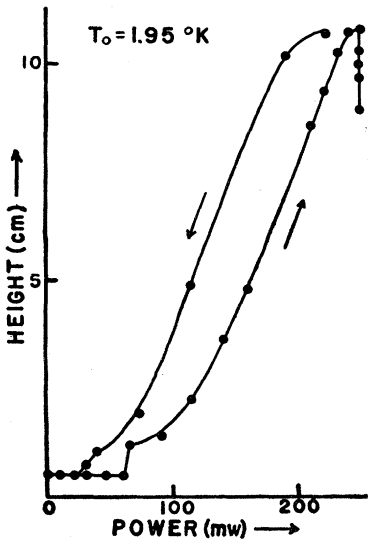

FIG. 2. Plot of the height of the inner liquid helium level above an arbitrary zero as a function of heater power input in milliwatts.

Figure 2 is a typical plot of the height of the inner helium level as a function of heater power (milliwatts). As the power was increased from zero there was at first a slight decrease in level which one would expect as the density of helium II increases with increasing temperature. At a certain power (here 61 mw) the level suddenly rose and continued to rise with increasing power until the temperature of the liquid above the frit exceeded the λ point. Here bubbling and a geyser effect took place. On decreasing the power it was found that the level was higher than on increasing power for the same value of power. However, at low powers the level returned to its original height.

The following results were found. (1) There is a linear relationship between power and temperature difference at low powers. The relationship becomes nonlinear in the power region in which the level begins to rise. (2) In the region of the level rise, the height is proportional to the temperature difference. (3) The level rise for a given temperature difference is much less than for the normal fountain effect.[2,3]

It might be reason that the rise in level follows from the formation of a gas bubble in the gaps between the rouge particles. There are two points which tend to rule out this possibility. One is that there is no drastic change in the thermal conductivity and the other is that no bubbles were ever seen in the gap which eventually developed between the frit bottom and the top of the rouge. To eliminate the possibility that the frit was responsible for the effect and to demonstrate the necessity of the small channels in the rouge, a run was made with a similar apparatus minus the rouge. The only level change observed in this case was a continual decrease in height with increasing power and temperature difference as one would expect from the density-temperature dependence.

To test the hypothesis that this effect was less than the normal thermomechanical effect because of a downward Hooke's law type tension, runs were made with the identical apparatus except that the glass tube above the frit was replaced by one of different cross-sectional area. It was found then that it was more nearly the volume increase in the tube which corresponded to a given temperature difference rather than the height (or pressure).

The "difference" forces acting on a cross-sectional area of the channels in the rouge are considered to be (1) a downward hydrostatic force resulting from the level rise, (2) a downward force resulting from the increase in temperature and hence an increase of vapor pressure of the liquid above the frit, (3) an upward thermomechanical force ($\rho S\Delta T\times$area), and (4) a downward force proportional to the ratio of the elevated volume to the volume of liquid in the rouge (volume strain). The first two are small compared to the last two. A "compressibility" is then calculated.

TABLE I. Summary of data.

Run	Bath temperature (°K)	Tube cross-section area (cm²)	Slope height *vs* temp. diff. $H/\Delta T$ (cm/°K)	Compressibility (atmos^{-1})
1	2.001	0.128	121	0.30
2	1.950	0.128	115	0.29
3	1.946	0.398	59	0.46
4	1.821	0.128	100	0.30
5	1.817	0.398	43	0.35

Table I is a summary of some of the data. Comparing runs 2 and 3 which were made at about the same temperature, it is seen that the value of $H/\Delta T$ is less for the run with the wider tube; the same comparison may be made for runs 4 and 5. The last column lists the calculated "compressibility." The order of magnitude is to be noted—the normal compressibility of liquid helium is approximately 1.3×10^{-2}/atmos.[4] Thus this "compressibility" is about 25 times the normal compressibility.

The "open" fountain effect was measured after a hole was drilled in the brass plug; the experimental result agreed substantially with that calculated from H. London's equation.

The author wishes to express his appreciation to Professor P. R. Zilsel for many interesting discussions and to Mr. Harold Forstat, Mr. John Reppy, and Mr. Russell Southwick for much help with the experiments.

Further work is in progress and a detailed paper will be submitted shortly for publication.

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† An earlier report was given as a ten-minute paper before the New England Section of the American Physical Society at Storrs, Connecticut, Nov. 7, 1953 and at the Third International Low Temperature Conference at the Rice Institute, Dec. 17–22, 1953.

[1] H. London, Nature **142**, 612 (1938); Proc. Roy. Soc. (London) **A171**, 484 (1939).
[2] P. L. Kapitza, J. Phys. U.S.S.R. **5**, 59 (1941).
[3] W. H. Keesom and G. Duyckaerts, Physica **13**, 153 (1947); J. H. Mellink, Physica **13**, 180 (1947); L. Meyer and J. H. Mellink, Physica **13**, 197 (1947).
[4] W. H. Keesom, *Helium* (Elsevier Publishing Company, Amsterdam-London-New York, 1942), pp. 236, 243.

Temperature Dependence of Ferromagnetic Resonance Line Width in a Nickel Iron Ferrite: A New Loss Mechanism

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WE have measured the ferromagnetic resonance line width in the [111] direction on two single-crystal spheres of a nickel-iron ferrite at 24 000 Mc/sec as a function of temperature from the boiling point of helium to approximately 400°K. The composition of these crystals, which were obtained from the Linde Air Products Company, was approximately $(NiO)_{0.75}(FeO)_{0.25}$